

Hudson River Paleoecology from Marshes: Environmental Change and Its Implications for Fisheries

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Abstract.—Hudson riverine and coastal marshes provide a paleoecological archive consisting of information on climate and land use at both the local and watershed scales. The timing of formation of these marshes is documented using accelerator mass spectrometry (AMS) ^{14}C dating of identified plant macrofossils in basal marsh organic sediments. While the Staten Island marsh is oldest and dates to 11,000 years before present (BP), Piermont, Iona, and Croton marshes date to the mid-Holocene, and the Jamaica Bay marshes formed most recently. Pollen and spores, charcoal, and plant macrofossils in the marsh sediments document marked climatic shifts as well as anthropogenic impact in the region. Assessment of the inorganic and organic content of the sediments in the marshes reveals a pattern of decreasing inorganic supply with the arrival of the Europeans, possibly due to the construction of numerous Hudson River tributary dams. Piermont Marsh, because of its sensitive location in the Hudson River, records droughts and wet intervals through species which have specific salinity affinities. Throughout the marsh records, the ragweed *Ambrosia* pollen rise marks the anthropogenic impact at the landscape scale. The recorded changes in hydrology and salinity that occurred throughout the centuries and millennia would have had profound effects throughout the food web and estuarine ecosystem. Fish populations would have been affected by changes in the food supply due to shifts in runoff affecting turbidity and light penetration in the river. Local vegetation changes within marshes may also have affected juvenile fish populations.

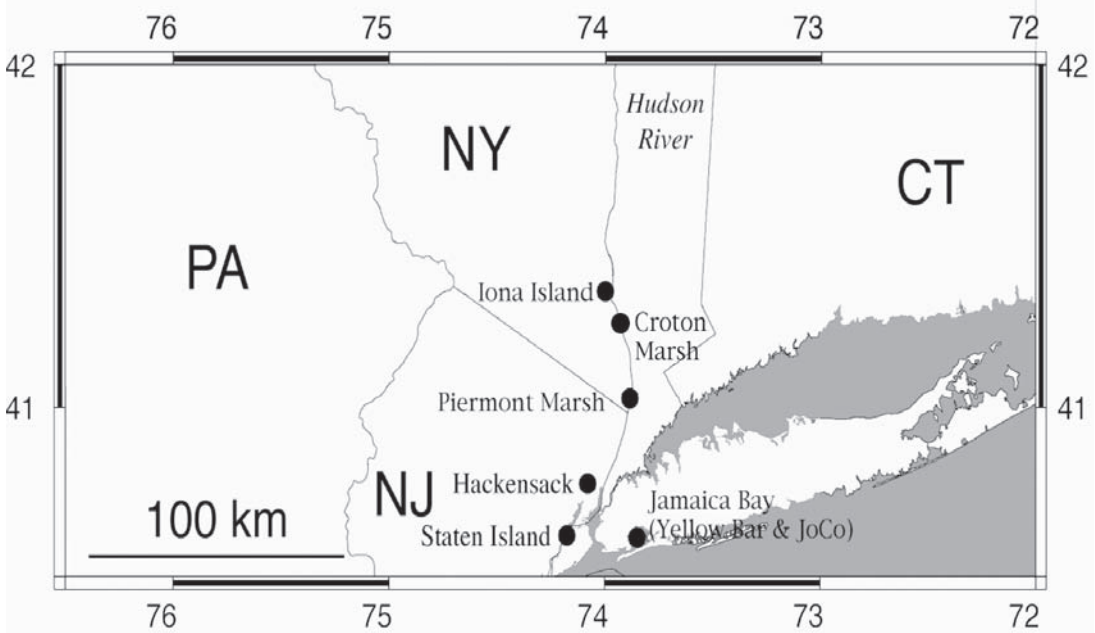


Figure 1. Suite of Hudson River tidal marsh sites from which we have collected cores.

Introduction

Tidal river marshes, among the most productive ecosystems in the world, are ecologically important for providing a nursery habitat for aquatic biota, protecting the shoreline, and mitigating floods. However, they are also unique archives of past environmental conditions in the estuary. Unlocking the history of regional vegetation and local marsh species reveals a wealth of information concerning past climate and biodiversity for the Hudson landscape. Despite decades of paleoenvironmental research on Atlantic seaboard tidal marshes, including the Chesapeake (Brush et al. 1982; Brush 1984, 1986, 1989; Willard and Korejwo 1999; Pasternack et al. 2001; Willard et al. 2003) and along the Connecticut coast (Thomas and Varekamp 1991; Varekamp and Thomas 1998), very little is known about the history of Hudson River estuarine marshes, with previous paleoecological studies limited to exploratory stratigraphic study (Newman et al. 1987; Wong and Peteet 1999). However, extensive wetland losses

have occurred throughout the estuary, and, in Jamaica Bay, approximately 25% of the original marsh remains after human development in this century alone (Englebright 1975). Estimates of the percent marsh loss in three remaining Jamaica Bay salt marshes from 1959–1998 is about 12% (Hartig et al. 2002). These losses in biota including invertebrate, fish, and bird habitat signal a decline in the health of the estuary.

The adjacent Long Island pollen, spore, and macroscopic marsh investigations include records back to about 500 years ago (Heusser et al. 1975; Clark and Patterson 1985; Clark 1986), where human influence is recorded in the uppermost sediments. The nearby Hackensack marshes (Figure 1) also record substantial shifts in native vegetation in the pollen and macrofossil records that have been interpreted from several sites. Heusser (1949, 1963), and more recently, Carmichael (1980), documented the 2,500-year history of vegetational change in the Hackensack tidal marsh (Meadowlands), New Jersey. The peat stratigraphy there traces the develop-

ment of the marsh from a freshwater alder swamp to a brackish marsh with frequent tidal inundation. The Hackensack Meadowlands macrofossil record shows a large impact of Europeans on the region as common reed *Phragmites* and narrow-leaf cat-tail *Typha* seeds replace members of the Cyperaceae family (*Scirpus*, *Cyperus*, *Eleocharis*) in upper sediments (Carmichael 1980). The increased biodiversity exemplified by the Meadowlands prior to major impact of invasive species illustrates the major shift in plant communities providing habitat for the tidal food web.

Our goals are to describe the age of formation of the lower Hudson tidal marshes, to review significant recent findings that have been documented in them, and to evaluate the importance of drought for the future of biota in the estuary. Particular emphasis is given to the role of anthropogenic influence in the estuary, and its ongoing effects on vegetation and the marsh environment. Specific questions we address are

- 1) What are the ages of the lower Hudson tidal marshes and how deep is the peat sequestered in them?
- 2) What is the history of inorganic and organic content in the Hudson marshes over time?
- 3) What do the marshes record about vegetational and climate change in New York and New Jersey?
- 4) What is the relationship of Hudson Marsh stratigraphy to previous regional paleoclimate records?
- 5) How are paleoecological shifts as indicated by Hudson marshes important for fisheries, especially in light of future droughts?

Hudson Marsh Importance for Paleoenvironmental Studies

Unlike river bottom sediments, which are subject to frequent erosion and redeposition, most marshes are dynamic in that their growth can keep pace with sea level and provide a fairly constant and uninterrupted record of sediment accumulation. In contrast to most coastal marshes of the northeastern United States, which are characterized by a thin blanket of sediment ranging from 2 to 3 m in depth (Niering et al. 1977; Varekamp and Thomas 1998), sedimentary profiles in marshes of the Hudson River can be very deep, ranging from 10 to 12 m over the last 4000–6000 years (Newman et al. 1987; Wong and Peteet 1999; Peteet, unpublished data). These high-depositional estuarine wetlands provide the ideal environmental setting for identifying abrupt short-term shifts in climate because of the opportunity to sample at high temporal resolution. Brackish marshes are also extremely sensitive to shifts in salinity.

Riverine marshes are largely controlled by the hydrologic regime, which can be highly variable, depending on the balance between water inputs (e.g., precipitation, snowmelt) and outputs (evaporation, evapotranspiration) (Mitsch and Gosselink 1993). The Hudson estuary has an extremely low stability ratio (0.4) which is defined as the ratio of the volume of an estuary (in km³) to the mean flow of freshwater in m³/s into the system (Simpson et al. 1973). This means that it has a very rapid response to storms and hurricanes, with the salt front moving long distances very rapidly (Cooper et al. 1988). Salinity is the dominant factor in determining the distribution of most plant species along the estuarine gradient (Odum 1988). Riverine marshes such as Piermont, Croton, and Iona Marsh in the lower Hudson (Figure 1) thus are probably the most sen-

sitive marshes on the East Coast in terms of major shifts in salinity from sustained droughts. Species composition, plant cover, and allocation of aboveground and belowground biomass in marshes can shift markedly and rapidly in response to hydrologic changes (Dunton et al. 2001). A suite of marshes along a salinity gradient thus provides a powerful resource to link stratigraphic changes throughout the lower estuary, also enabling a better understanding of the processes that link the sites in the adjacent uplands in the watershed to deposition in the marshes.

Hudson Marsh Sites and Regional Marsh Records

We now are working on a suite of cores from tidal marshes in the Hudson estuary (Figure 1) ranging from the Hudson mouth (Staten Island, Jamaica Bay) to about 70 km upriver (Iona Island). The sites described here, from south to north, include the Jamaica Bay JoCo and Yellow Bar marshes, Arthur Kill Marsh in Staten Island, Piermont Marsh, Croton Point Marsh, and Iona Island Marsh. These are all tidally influenced but arrayed at increasing distances from the New York Bight along a wide salinity gradient. Plants characteristic of the marshes range from typical maritime salt meadow cordgrass *Spartina alterniflora*, salt meadow hay *S. patens*, and inland saltgrass *Distichlis spicata* in the coastal marshes (Jamaica Bay, Staten Island) to the more brackish marshes that have higher species diversity (Winogron 1997) with a large component of narrow-leaf cattail and bulrush *Scirpus* species (Piermont, Iona) as well as the ubiquitous common reed. Recent research on the modern plant communities and their dramatic changes due to human impact in the last few decades is best documented in Piermont, one of the

four National Estuarine Research Reserve (NERR) sites in the Hudson River. From 1965–1991, common reed colonies increased their coverage of the marsh from 35% to 66%, destroying much of the biodiversity which characterized this brackish setting (Lehr 1967; Winogron 1997). The pattern of common reed invasion in recent decades (Carmichael 1980; Clark and Patterson 1985; Wong and Peteet 1999; Pederson et al. 2005) suggests that it is a result of human impact, and its recent dominance has been attributed to introduced varieties that vary genotypically from the native types (Saltonstall 2002).

Methods

Tidal marsh sites were cored manually using primarily the modified Livingstone piston corer (Wright et al. 1984), which is 5 cm in diameter. To retrieve the top meter of the sediment, which is sometimes problematic with the Livingstone, a clear plastic pipe was hammered into the peat and dug out with a shovel and the Hiller peat corer was used to eliminate compaction.

Chronological Control

We use ^{137}Cs for dating of the “bomb spike” in 1963, and Accelerator Mass Spectrometry (AMS) radiocarbon dating of in situ plant macrofossils, which is the best possible method of dating this type of stratigraphy. Because the seeds take in carbon from the atmosphere, there is no correction for marine or terrestrial old carbon which results in a large uncertainty in estuarine cores (Colman et al. 2002; Rubenstone and Peteet, Lamont Doherty Earth Observatory, unpublished). Radiocarbon dating of basal organic material just atop mineral matter indicates the time of formation of the marsh in the estuary.

Sediment Stratigraphy, Loss-on-Ignition (LOI)

All sediment cores are described in terms of the sediment type (peat, silt, clay) and weighed samples are dried overnight and then combusted at 450°C to determine percent loss-on-ignition (LOI) (modified from Dean 1974). The LOI values are a proxy for organic content and, hence, the carbon content of the cores. Carbon accumulation rates can then be calculated using dry bulk density of the sediments and precise sedimentation rates calculated from AMS ¹⁴C dates in the cores.

Pollen and Spore Analysis, Microscopic Charcoal

Samples were processed for pollen and spores using the procedures of Heusser and Stock (1984), which include soaking the samples in KOH, HF, screening with 7- and 150-mm screens, and the use of glacial acetic acid, acetolysis mixture, and silicone oil mounts (Faegri and Iversen 1975). Exotic *Lycopodium* tablets were added to the samples to determine pollen concentration. A minimum of 300 pollen grains were counted and all palynomorphs tallied; where local pollen was abundant, we counted at least 300 upland types. Pollen identification was aided by a modern reference collection and reference books (Faegri and Iversen 1975; Moore and Webb 1978; Lewis et al. 1983). Both percentage and influx diagrams were constructed using TiliaGraph (Grimm 1992). Microscopic charcoal pieces greater than 50 µm x 10 µm (500 µm²), used to infer fire (Clark and Patterson 1985) were counted along with pollen grains and *Lycopodium*. Charcoal: pollen ratios (C:P) were calculated for the Piermont core to clearly demonstrate the role of this disturbance at the site:

$$\text{C:P} = \frac{\text{charcoal area } (\mu\text{m}^2)}{\text{\# pollen grains}}$$

Plant Macrofossils, Foraminifera, and Charcoal

Macrofossils were analyzed according to the procedures of Watts and Winter (1966). This includes soaking samples in 10% KOH overnight to disaggregate the sediment, then washing them through 500- and 150-µm brass screens. Plant macrofossils are a crucial component of the vegetation reconstructions because they can be identified to the species level and, therefore, more definitively portray the ecological conditions. They unequivocally establish the presence of a species at the site, and selected macrofossils are used for AMS ¹⁴C dating to give precise timing of changes in vegetation and climate through time. Tidal marsh peat is composed of peat rhizomes as well as reproductive plant parts. Keys such as Niering et al. (1977) were used to identify peat types in the samples. Foraminifera were screened and picked in water, then identified to assess salinity changes for selected samples. Charcoal pieces larger than 500 µm were counted as part of the macrofossil analysis.

Results and Discussion

What is the age of the lower Hudson tidal marshes and how deep is the peat sequestered in them?

From 1998–2003, cores were extracted from marsh sites throughout the lower Hudson River, ranging from Jamaica Bay at the mouth of the estuary (Figure 1) to Iona Island, about 70 km north of the Battery. Table 1 documents peat depth and basal core age from the suite of Hudson marshes where sediment cores have been extracted, peat depths recorded, and basal peat ages determined through AMS ¹⁴C dating on identified plant macrofossils contained in the sediment cores. At all sites except Piermont, inorganic sediments were identified as basal

Table 1. Location, peat depth, and basal ^{14}C age of Hudson marshes.

Tidal Marsh	Latitude/ Longitude	Peat Depth	Basal ^{14}C Age
JoCo	40° 37'N	2 m	>460 <2000
Jamaica Bay	73° 47'W		
Yellow Bar	40° 37'N	0.8 m	>450
Jamaica Bay	73° 50'W		
Arthur Kill	40° 36'N	8.0 m	11,100
Staten Island	74° 13'W		
Hackensack	40° 48'N	3.7 m	2,610
New Jersey	74° 04'W		
Piermont N	41° 00'N	13.7 m	5,700
Piermont	73° 55'W		
Croton Marsh	41° 14'N	10 m	4,630
	73° 50'W		
Iona Marsh	41° 18'N	10 m	5,500
	73° 58'W		

mineral matter on which the marsh generation took place. The large variability in peat depth and age suggests that the origin of marsh formation is quite diverse. Basal dates from two Jamaica Bay sites indicate that the Jamaica Bay marshes were formed within the last millennium, suggesting that they likely owe their origin to recent protection of the area from open ocean wave action.

In contrast, Staten Island's Arthur Kill marsh at the same latitude is older than the estuary itself, as its freshwater sediments reveal a fossil assemblage including violet *Viola*, pondweed *Potamogeton*, and alder *Alnus* seeds and willow *Salix* buds, indicating an age of 11,100 years. The freshwater origin of the Arthur Kill marsh in Staten Island is significant because it predates sea level rise to the site. Additional implications for this study include interpretations of the timing of isostatic uplift in coastal New York or changes in river channel geomorphology.

Of much younger origin than the Arthur Kill marsh are the upriver brackish sites such as Piermont, Croton, and Iona Island

marshes. These wetlands all formed in the mid-Holocene, probably due to the influx of the marine water into the Hudson River canyon as eustatic sea level rose and isostatic rebound favored marshes keeping pace with sea level. The basal material from Piermont (13.77 m) lacks any identifiable macrofossils, but the oldest age obtained from seeds is 5,700 years (at 13.70 m depth). We have not yet reached the base of the marsh at this site. Basal material from the Croton Point marsh (10 m core) includes fibrous woody material, Foraminifera, and *Zanichellia* seeds and other brackish vegetational components. The basal sediment from the Iona Island (10 m core) has vegetation such as *Scirpus* and *Cyperus* seeds, implying a brackish environment. Reasons for the remarkably high sedimentation rate at Piermont marsh includes possible basal clay compaction below the marsh itself, high plant production due to river and marine nutrients at the site, and tectonic activity. The generation of these marsh sites would have substantially increased the nursery habitat for those fish that use these habitats for food and protection of young. This study provides the groundwork for more

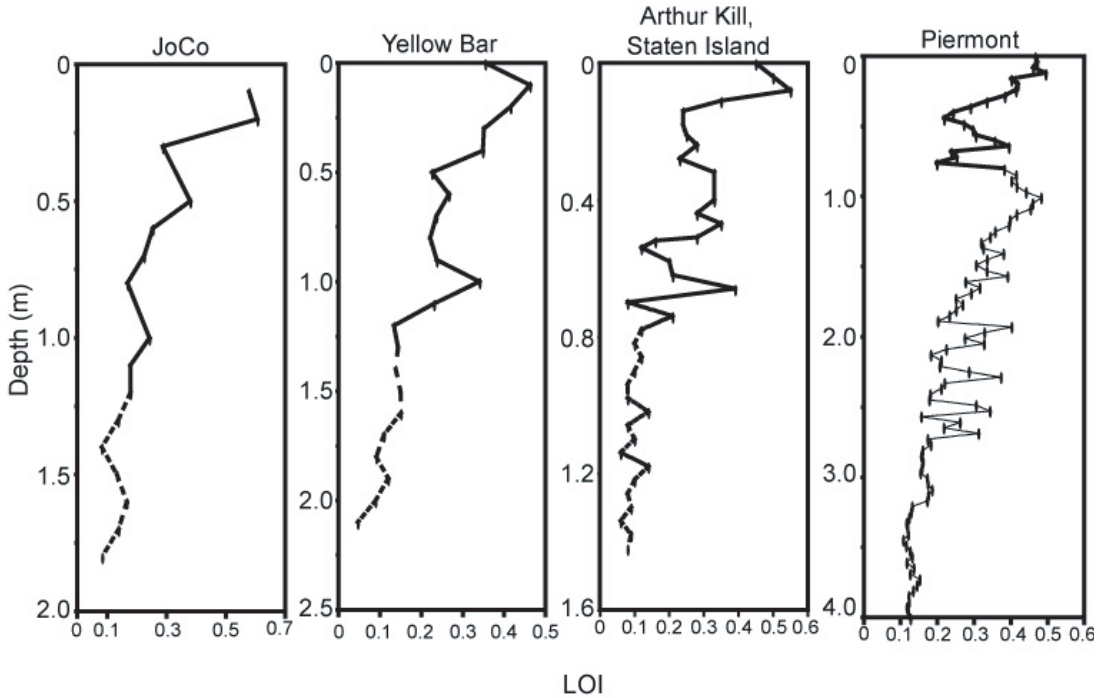


Figure 2. Loss-on-ignition (LOI) with depth for four tidal marsh sites in the Hudson Estuary. Solid line indicates anthropogenic impact. Between 0.8–1.2 m depth in each core, pollen analysis and ^{14}C dating indicates European arrival, and the organic percent increases with fluctuations up to the present

high-resolution studies of these marshes to understand the fluctuations in salinity caused by climate (i.e., precipitation and evaporation) or possibly tectonic change or relative sea level rise.

What is the history of inorganic and organic content in the marshes?

Marsh LOI profiles (Figure 2) indicate a significant increase in percent organic matter from the arrival of Europeans to the uppermost modern sediment. However, subsequent research on masses in all of the marshes (Figures 3 and 4) indicates that the trend of increasing LOI with European arrival results from a dramatic decline in inorganic content instead of an increase in organic content. The Yellow Bar, Jamaica Bay core (Figure 3) shows a sharp decline in inorganic content at 110–115 cm, the same interval as the European impact as shown

from the ragweed rise (Peteet unpublished). The last 1500 years in Piermont Marsh (Figure 4) demonstrates a fairly constant organic content while the inorganic content is much greater during the Medieval Warming in the lower part of the diagram (230–160 cm), probably due to increased upland runoff, and in contrast increases only slightly in the settlement era between 76 and 36 cm (Pederson et al. 2005).

One hypothesis for the decline in inorganic flux to the sites with anthropogenic influence is the construction of numerous dams on the Hudson tributaries by the settlers and continuing to the present, with almost 800 remaining to this day (Swaney et al. in press). While the dams would have blocked the heavier inorganic sands and silts, the lighter organic material would continue downriver with the flow. Other possibilities include changes in source contributions from

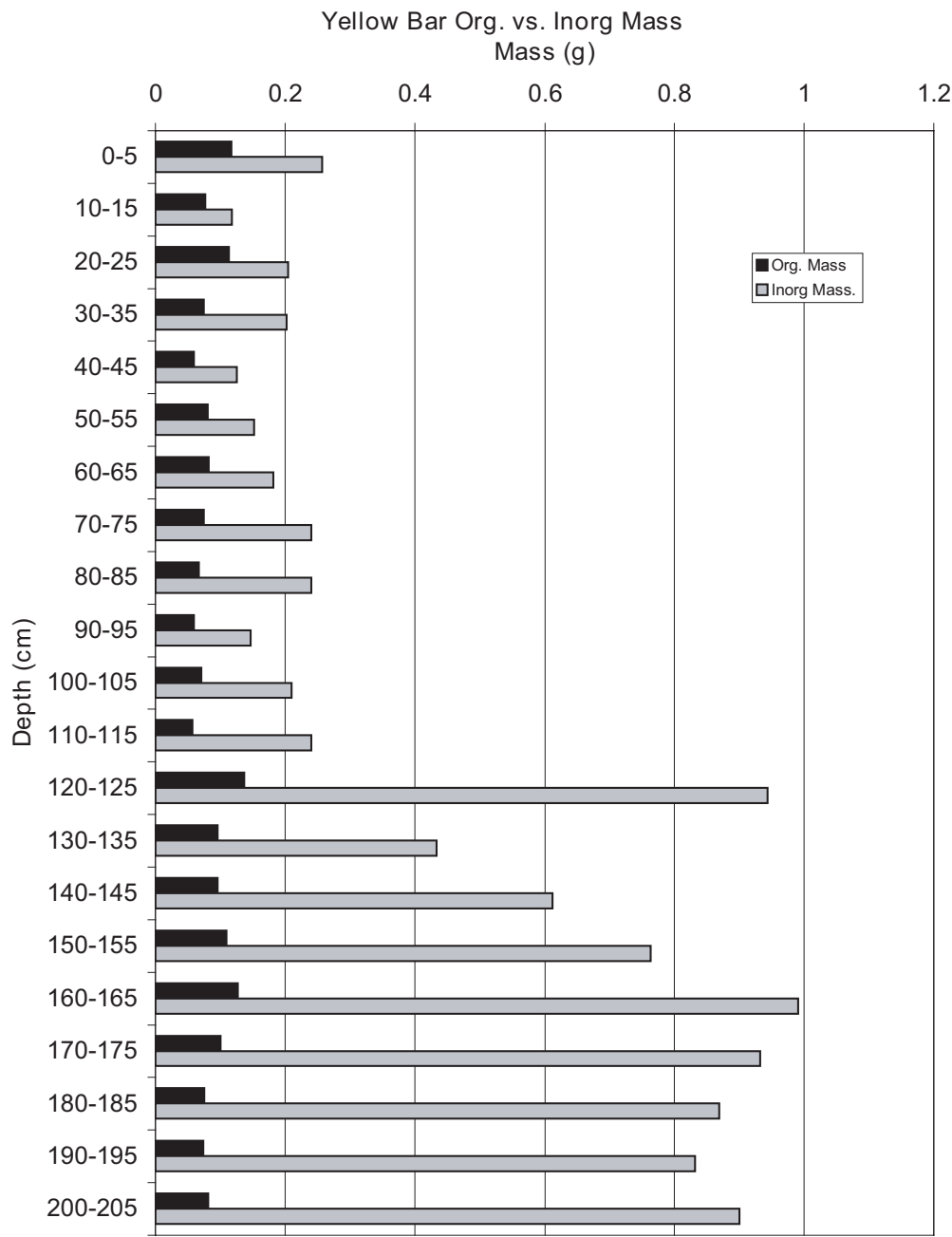


Figure 3. Sediment component masses based on dry sample mass in Yellow Bar, Jamaica Bay core. Inorganic content drops sharply at 110 cm with European impact.

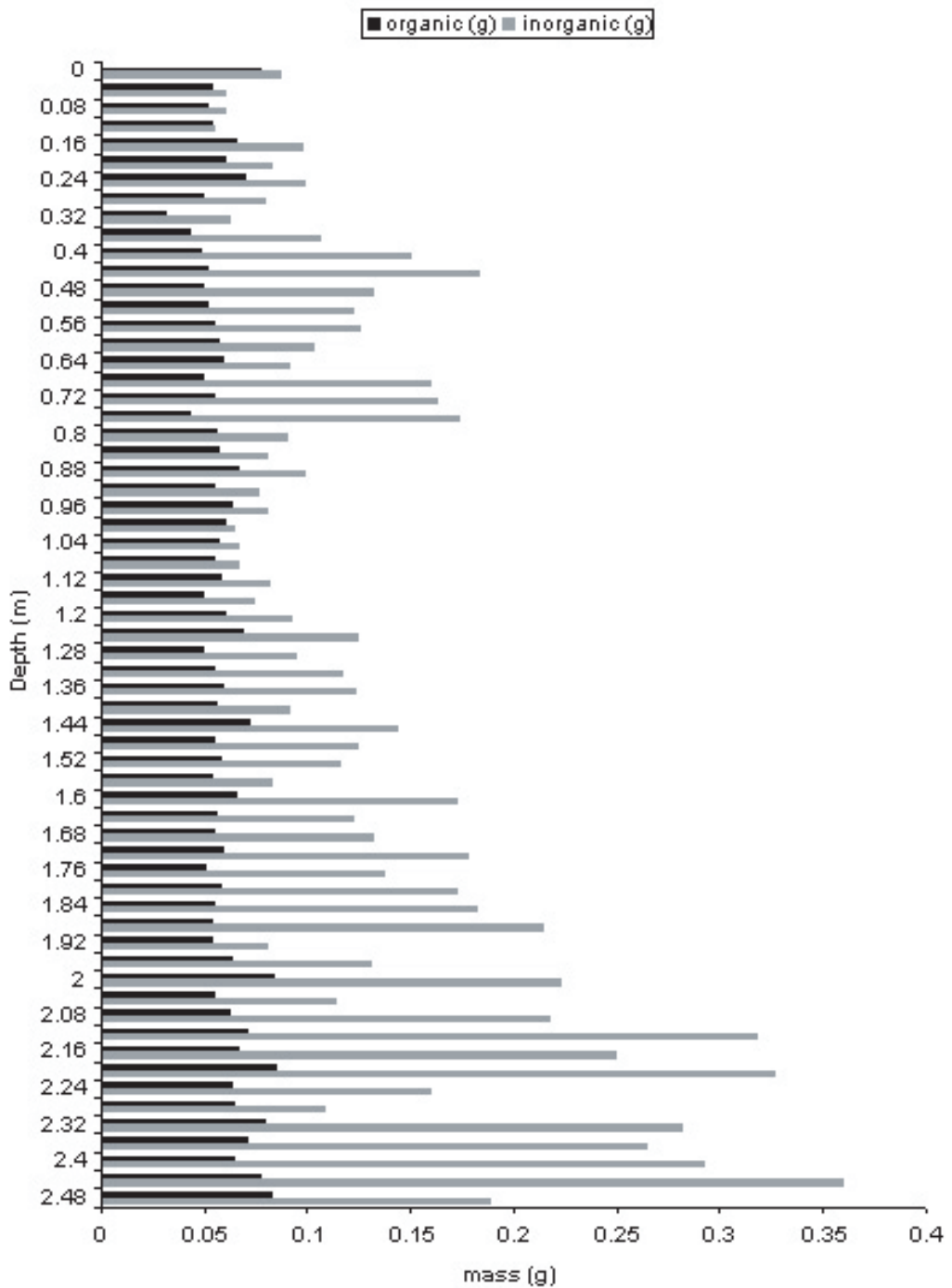


Figure 4. Sediment component masses based on dry sample mass in upper portion of northern Piermont Marsh core. While the Medieval Warm interval from 230 to 160 cm has relatively high inorganic mass, the upper settlement era of high ragweed (*Ambrosia*) from 76 to 36 cm also has a slight increase in inorganic mass (adapted from Pederson et al. 2005).

the watershed with land use change, although land use changes with settlement in the Chesapeake estuary resulted in major increases in inorganic sediment as well as eutrophication which increased sedimentation rates (Cooper and Brush 1991). A third possibility is that local vegetational shifts changed the matrix for trapping inorganic sediments.

What do the marshes record about regional vegetational and climate change?—Example from Piermont Marsh

Piermont Marsh (40 °00 N, 73 °55 W), protected by the Hudson River National Estuarine Research Reserve (HRNERR), extends over 110 ha, is about 40 km north of the southern tip of Manhattan, and is bordered on the west by Tallman State Park (Figure 1). The mean tidal range of the marsh is 0.98 m and the mean salinity is 6 practical salinity units (psu) (Winogrand 1997). Piermont Marsh is the northernmost marsh on the Hudson River with native salt-tolerant marsh grasses (Lehr 1967). We have two existing cores in the high marsh communities (*Spartina patens*, *Distichlis spicata*) from the site. In 1998 we retrieved a 11.2 m core from the site with an AMS date at that depth of 4100 ¹⁴C yr BP. Subsequently, we retrieved additional sediments in the same hole down to 13.77 m with an AMS date on seeds of 5700 ± 45 ¹⁴C yr BP. A second core site in the southern portion of the marsh was sampled in 2001. Preliminary exploratory study of Piermont Marsh, Piermont, NY (Wong and Peteet 1999) resulted in coarse analysis of the top 11 m (4100 ¹⁴C yrs) of the northern Piermont core at a 1-m resolution. This preliminary study reported the occurrence of a wide diversity of marsh macrofossils which record variations in salinity (freshwater aquatics such as *Chara* and *Nitella* versus halophytes such as *Salicornia* in the Chenopodiaceae). Large

changes in charcoal abundance are present, as well as variations in high marsh Foraminifera such as *Trochammina macrescens* and higher salinity low marsh *Elphidium*. Preliminary pollen analysis, also at the 1-m resolution, showed major shifts in pollen percentages downcore, with intriguing, extremely high *Tsuga* (hemlock) pollen percentages near the base of the core. Subsequent ongoing higher resolution of macrofossils (not completed) on a 2.2-m section of the core (11.2–9 m depth, 4200–3400 ¹⁴C years BP) indicates rapid environmental changes, illustrated at about 940 cm depth by a dramatic drop in LOI from 80% to 10%, the disappearance of Foraminifera and charcoal particles, and the dominance of freshwater algae fossils. We interpret this change as indicating increased river flow and higher precipitation alternating with intervals of low river flow (more Foraminifera, higher charcoal, drought). We have also identified *Salicornia* and charred *Scirpus* seeds in these drought intervals. The presence of *Salicornia* is especially important because it does not grow in Piermont Marsh today, presumably because the site is too fresh.

Pederson et al. (2005) investigated the paleorecord from Piermont marsh at the bi decadal scale over the last 1500 years. The simplified pollen and spore diagram (Figure 5) from stratigraphy in Pederson et al. (2005) documents both climatic and land use change. Our downcore LOI values range between 20% and 60% (Figure 5), suggesting that the surface was always marsh and not subject to channel erosion, as our measurements indicate modern channel sediments have an LOI value of 5%. The last millennium of marsh history also includes a striking drought from about 800–1300 years BP (Zone P-1, Figure 5), as demonstrated by high values in more drought-tolerant pine *Pinus* and hickory *Carya* concurrent with low values in oak *Quercus* and other more drought-sensitive species such as hemlock

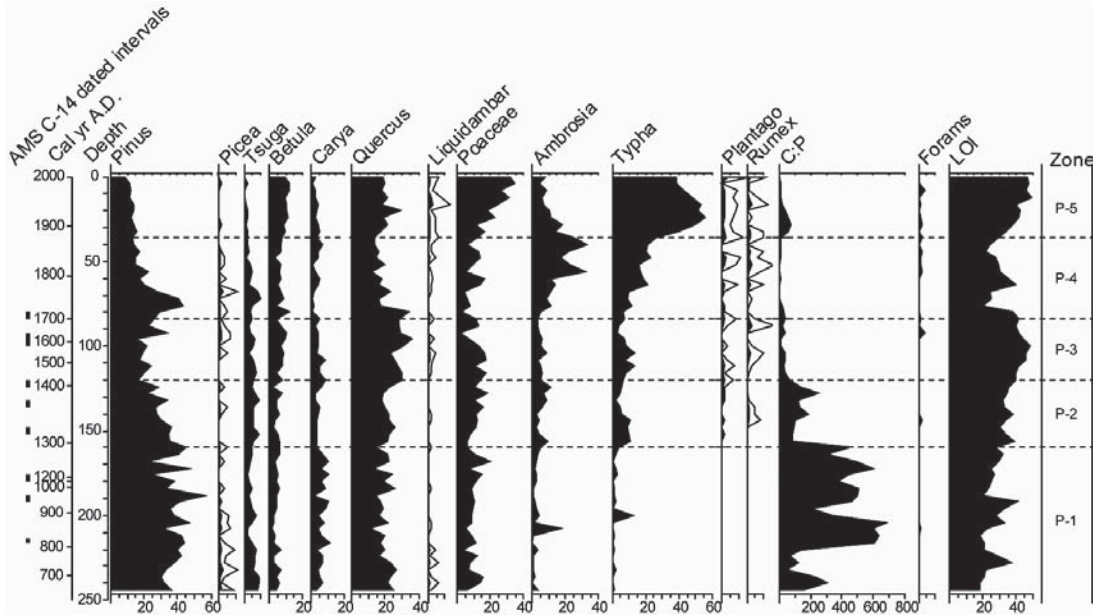


Figure 5. Pollen and spore percentage diagram of selected taxa along with Foraminifera and LOI from upper portion of northern Piermont core (adapted from Pederson et al. 2005).

Tsuga and birch *Betula*, large increases in charcoal, low pollen accumulation, and the absence of Foraminifera (Pederson et al. 2005).

What is the relationship of Hudson marsh stratigraphy to previous regional paleoclimate records?

The timing of this dry period in Piermont corresponds to the classic Medieval Warm Period (MWP) as defined by Lamb (1982) to be between approximately A.D. 800–1200. We have correlated this drought in our region with salinity records from Chesapeake Bay (Cronin et al. 2000; Cronin et al. 2003), pollen records from lakes and ponds in Massachusetts (Fuller et al. 1998), and tree ring records of east coast drought (Stahle et al. 1988). Cronin et al. (2000) noted that large fluctuations in salinity in the Chesapeake estuary included 14 wet–dry cycles in the last 500 years, including 16th and early 17th century megadroughts that exceeded 20th century droughts in their severity. Cronin

et al. (2000) further stated that these salinity oscillations equate to changes in regional precipitation and streamflow of 40–50% if relationships among rainfall, streamflow, and salinity were similar to those of the last 200 years. The consequences of severe and prolonged droughts for the future of the lower Hudson and the character of the estuarine habitat would be extreme. Determining the presence of such sustained droughts is particularly critical to evaluate their potential future effects on the Hudson estuary, both in the open river and in the wetland communities.

How are paleoecological shifts indicated by Hudson marshes important for fisheries, especially in light of future droughts?

Freshwater flow may be the single largest factor influencing trophic functioning in the Hudson estuary (Gladden et al. 1988). The food web is supported by allochthonous carbon input (69% of total) as well as phy-

toplankton and submersed macrophytes (Howarth et al. 1996; Caraco et al. 2000). Our results demonstrate that major changes in the hydrological cycle have taken place over millennia, with long-term megadroughts that must have affected the entire estuary as well as the local marsh biota. As Howarth et al. (1991) noted, carbon and sediment inputs to the estuary have major influences on ecosystem metabolism and light penetration. Larvae and juveniles of many fish in the Hudson feed heavily on plankton and drifting benthic invertebrates in the water column (i.e., American shad *Alosa sapidissima*, blueback herring *Alosa aestivalis*, alewife *Alosa pseudoharengus*, striped bass *Morone saxatilis*; Strayer and Smith 2001). Strayer et al. (2004) have shown that freshwater flow is significantly correlated with distributions of many fish species in the Hudson. In years of higher freshwater flow, in general, fish populations are centered further downriver and reveal slow apparent growth. The increased flow in wet years presumably is responsible for poor development of phytoplankton because of high advective losses and light limitation (Caraco et al. 1997; Pace and Lonsdale 2005). Drought years with increases in salinity would favor movement of open water fish upriver (Strayer et al. 2004).

However, large watershed changes such as drought and fire contribute sediment in runoff that affects river turbidity, resulting in deposition of high numbers of inorganic particles in the marshes, as demonstrated by the Piermont record (Pederson et al. 2005). Thus, while Howarth et al. (1991) proposed that sediment fluxes were much lower prior to European settlement, our data indicate that inorganic flux prior to European settlement was much higher, especially during the Medieval drought. Depending on the grain size of the inorganic material in suspension, light may have been more limited than today. A focused research ques-

tion is to determine the phytoplankton contribution to the food web in drought years with high inorganic runoff.

The composition of the river benthic communities is clearly a strong function of salinity (Strayer 2005). While marine animals such as the bivalves *Mya* and *Macoma* dominate in the river near its mouth, above Newburgh the benthos is dominated by freshwater species of oligochaetes, insects, and bivalves. However, the brackish zone is characterized by a blurring of the fauna along the salinity gradient (Simpson et al. 1984; Strayer 2005), suggesting that wet and dry years shift the biota. Sustained droughts would have favored movement of the benthic communities upriver as well as the open water fish.

Tidal marsh resident fish such as various killifishes (*Fundulus* spp.) and caridean shrimps (*Palaemonetes* spp.) would also be affected by drought. The spotfin killifish *Fundulus luciae*, although reported from salt and brackish marshes of the eastern United States, was found only recently in Piermont Marsh in the upper intertidal regions (Yozzo and Ottman 2003). At Piermont, increased rainfall throughout the season was thought to increase the retention area for killifish in small ponds in the upper marsh area (Yozzo and Ottman 2003). Sustained drought would thus presumably limit the distribution of these fish in the tidal marshes.

Drought would also affect the local food web in the marshes because of the shifts in plant composition, as well as aboveground and belowground biomass allocation of the vegetation in the marshes. Land use change since Europeans settled the region reveal the magnitude of the shifts that can take place over decades and centuries. For example, mixed communities of grasses and sedges in the Hackensack and Piermont Marshes were replaced by the dominant

dense common reed stands today (Carmichael 1980; Winogron 1997; Pederson et al. 2005). This replacement increased stem density, plant height, and detrital accumulation, which combine to reduce light at the marsh surface (Meyer et al. 2001). The expansion of common reed at the expense of salt meadow cordgrass has also been linked to the reduced frequency and duration of flooding in southern Connecticut salt marshes (Osgood et al. 2003) through increases in elevation and decrease in marsh microtopography (Windham and Lathrop 1999), which affected invertebrates and juvenile fish. In Piermont Marsh, nekton use of three common reed-dominated sites (erosional creekbank, depositional creekbank, interior) was comparable to that measured in wetlands elsewhere on the Hudson River, where common reed was not dominant (Hanson et al. 2002). A more recent study of Piermont and Iona marshes indicated reduced larval survival of mummichog *Fundulus heteroclitus* within common reed stands (Osgood et al. 2005). These authors suggest that this reduction in larval density could decrease secondary production within the system. Thus, the energy flow from the marshes would affect the open waters of the estuary.

In summary, our results suggest that the Hudson marshes have undergone large shifts in vegetation over centuries and millennia due to megadroughts and wetter time intervals which would have affected Hudson fisheries. While these long-term changes are natural, they are important for understanding future risks of climate change to the hydrology of the estuary and to the large urban populations in the lower Hudson Valley. The more recent anthropogenic impacts, such as the invasion of common reed, are important for diminishing biodiversity in the wetlands as well as reducing larval fishes and thus the food web in the larger estuary.

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